Survey of Air Force Landfills, Their Characteristics, and Remediation Strategies

July 1999

Prepared for:
Air Force Center for Environmental Excellence
Technology Transfer Division
(AFCEE/ERT)
3207 North Road
Brooks AFB, TX 78235-5363

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Executive Summary

The Air Force is responsible for a large number of landfills, each of which must be remediated, removed, or closed. These are costly undertakings, and informed decisions require an understanding of the existing situation, as well as a familiarity with alternative solutions. This report and the accompanying database are designed to support the Air Force and the Department of Defense (DoD) in the following ways:

- Estimate the number of Air Force landfills and characterizing them
- Provide a basis for assessing remediation requirements
- Provide a basis for new DoD landfill remediation strategies

Remediation

Most landfills are remediated by using accepted presumptive remedies to contain the wastes in place. An adequate cover or "cap" is an important component of the presumptive remedy that is commonly applied to landfills. Remediation activities may include control of gas generated in the landfill, soil vapor extraction, control of contaminated groundwater, and long-term groundwater monitoring. However, landfill covers are often the most expensive part of the remediation activity and influence the performance of any other remediation effort. Landfill covers are the focus of this report.

Landfill covers are required to minimize the amount of precipitation that may infiltrate into the waste and thus pose a threat to groundwater quality and to isolate the waste from receptors. Conventional presumptive remedies include the following covers:

- Barrier-type covers that use compacted clay or flexible plastic membranes, often called RCRA (Resource Conservation and Recovery Act) covers
- Compacted soil covers, often called Subtitle D covers

Conventional landfill covers are expensive to construct and maintain and are prone to leak after aging. There is the possibility that they may not perform adequately for as long as the waste must be stored. Alternative covers are needed that are effective over the long term and less expensive.

Alternative methods for landfill remediation are not currently in widespread use. However, these methods should be considered for use on military landfills because they may meet the requirements and reduce remediation costs. No further action is an alternative remediation method. Alternative landfill covers include the following:

- Alternative barrier-type components of covers
  - Capillary barrier
  - Dry barrier

  - Asphalt barrier
- Evapotranspiration (ET) Cover

Survey Results

The Air Force Center for Environmental Excellence (AFCEE) landfill survey data are stored in a compressed (zipped) Microsoft Access database file named "**AFCEE Landfill Survey.exe** . The self-extracting file occupies about 405 KB on a floppy disk. The instructions for opening, reading, modifying, or adding to the database are contained in Appendix C of this report.

The AFCEE landfill survey compiled for this report includes more than 40 percent of Air Force bases located within the continental United States. The data reveal the following about Air Force landfills:

- About 86 percent of the landfills were inactive for more than 20 years.
- Less than one percent of the landfills have bottom liners.
- Remediation is complete for 23 percent of the surveyed landfills.
- The average surface area of the landfills is about 13.3 acres.
- The climate at more than half of the bases surveyed is suitable for alternative covers.
- The "no further action" alternative was used for 12 percent of Air Force landfills.

This inventory of Air Force landfills serves as a basis for evaluation by the Air Force of current landfill status and condition and of available alternative remediation methods.

Using the Risk-Based/Performance-Based Approach for Remediation Selection

Risk-based/performance-based (RB/PB) selection of landfill remediation methods is a technical approach to identify protective measures based on the specific conditions at a landfill. Using the RB/PB approach allows the Air Force to select any technically sound action that meets the requirements for remediation. For example, the RB/PB approach is a logical way to correctly select "no further action" or other alternatives as the appropriate action.

Potential Cost Savings

The ET cover is used as an example of the savings that may result from using alternative covers in place of conventional covers. A conservative analysis revealed that appropriate use of the ET cover should result in construction cost savings of about $500 million and that the overall savings could reasonably be expected to exceed $750 million for the Air Force alone.

1 Introduction

The Air Force is responsible for a large number of landfills, each of which must be remediated, removed, or closed. These are costly undertakings and require an understanding of the existing situation, as well as a familiarity with alternative solutions. This report and the accompanying database are designed to support the Air Force and the Department of Defense (DoD) in the following ways:

- Estimate the number of Air Force landfills and characterizing them
- Provide a basis for assessing remediation requirements
- Provide a basis for new DoD landfill remediation strategies

The U.S. Air Force has used landfilling to dispose of a variety of wastes. These wastes include municipal solid wastes (household and/or office refuse), construction debris and rubble, industrial (shop) wastes, low-level radioactive wastes (including radioactive electron tubes), cleaning solvents, paint, paint strippers, and pesticides. Air Force landfills are usually trenches, pits, or other depressions in the earth into which waste has been deposited; few have a bottom liner. Practically every Air Force Base (AFB) has one or more landfills—usually of the trench-and-fill type. Most bases shifted from landfilling to contract waste disposal by the late 1980s.

The Air Force initiated the Installation Restoration Program (IRP) in the early 1980s to identify, characterize, and remediate past and present waste disposal sites. The IRP is now called The Environmental Restoration Program (ERP). The IRP/ERP was designed to be the military version of the civilian sector cleanup program mandated by the National Contingency Plan (NCP) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In 1986, CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA). Under SARA, appropriate DoD facilities were included under CERCLA, and it became the major legislation governing the remediation of many military waste disposal sites. The requirements of the Resource Conservation and Recovery Act (RCRA) apply to all landfills that were in operation on or after 19 November 1980, while CERCLA governs all landfills that were inoperative before that date. However, the requirements of RCRA Subtitle D (40 CFR 258.60) are often cited as applicable or relevant and appropriate requirements (ARARs) for landfill covers planned under CERCLA.

An adequate cover or “cap” is an important component of the presumptive remediation for most landfills. Conventional landfill covers are expensive to construct and maintain and are prone to leak after aging. It is possible that these covers may not last for the length of time that the waste must be stored. The Air Force needs alternative covers that are more effective in the long term and less expensive. This inventory of Air Force landfills will serve as a basis for evaluating the current situation regarding landfill remediation and the possible use of alternative covers by the DoD.

This report is based on the response to surveys sent to Air Force commands and/or bases. Mitretek personnel also completed a few survey reports from investigative reports. Some commands and/or bases did not respond. The data were entered into the Air Force Center for Environmental Excellence (AFCEE) landfill survey database as they were received on the completed forms. This report describes the AFCEE landfill survey and suggests its possible use to support the remedial decision-making process for military landfills. The landfill survey database is searchable and can be readily expanded.

Some analyses of the landfill data are contained in this report, along with evaluation of cost savings that could result from the use of one possible alternative cover. While the data are most pertinent to the Air Force; parallels can be drawn between the Air Force situation and other DoD branches. Therefore, the results of the survey have utility throughout the DoD.

This report and the database containing the survey results are complete in themselves. However, a description of the technology and an explanation of the appropriate regulations are presented in greater detail in a recently completed companion document, *Landfill Covers for Use at Air Force Installations* (AFCEE, 1999).

2 Landfill Remediation

The DoD service branches are responsible for numerous inactive landfills, each of which must be assessed to determine its need for remediation. Plans must be made and carried out for every landfill to ensure that human health and the environment are protected. There are typically three options for dealing with inactive landfills:

- **No Further Action (NFA).** If the landfill is not a threat to human health or the environment, the stakeholders (including local residents, regulators, and the landfill owner) may agree that no action is needed at the landfill.
- **Removal.** The landfill owner may excavate the entire contents of the landfill, properly dispose of the excavated material, and restore the site to acceptable environmental conditions. This action may result in closure of the site.
- **Remediation.** Remediation of a landfill generally means that the landfill waste is contained in place to prevent potential harm to human health or the environment. Remediation of a landfill usually requires a cover that limits water infiltration into the landfill waste and controls soil erosion from the landfill surface. Other remediation activities may include (1) control of gas generated in the landfill, (2) soil vapor extraction, (3) control of contaminated groundwater, and (4) long-term groundwater monitoring. Normally, remediation does not result in near-term closure of a landfill site because long-term maintenance and groundwater monitoring are generally required following the remediation phase.

Landfill contents, age of the waste, site geology, and construction methods affect the choice of remedial actions. Air Force landfill types include municipal solid waste, hazardous waste, and other types of waste, each of which is governed by different sets of regulations. Most Air Force landfills were constructed prior to the passage of RCRA, and only 1 of 229 landfills described in the AFCEE landfill survey was constructed with a bottom liner. Modern landfills are required to have a bottom liner under RCRA rules and regulations.

Placement of a cover on a landfill is sometimes referred to as landfill closure. However, few Air Force landfill sites are actually closed because closure requires elimination of the source of the contaminants; this makes site closure an expensive process. Consolidation is an available alternative that results in excavation of waste from small landfills and movement to a central location. The excavated sites may be closed.

Most Air Force landfills are remediated by containing the waste in place to limit and control the movement of contaminants from the landfill, including contaminants that may be generated by waste decomposition within the landfill. A suitable cover over the landfill is usually the most important and expensive part of the containment remedy. Landfill covers are required (1) to minimize the precipitation that may infiltrate into the waste and leach contaminants into the underlying groundwater and (2) to prevent potential receptors from coming into contact with the waste at the surface of the landfill.

2.1 Conventional Landfill Covers

To assist the reader, a brief description of landfill cover types is presented below. The reader should refer to AFCEE (1999) and other cited literature for details. Conventional, widely used, and approved covers for landfills include the following:

- **Barrier or RCRA Covers.** These covers consist of a series of layers, including (from the surface downward) a grass cover, a soil cover, a drainage layer, a barrier layer, a gas-collection layer, and fill (which lies immediately above the waste). The barriers may be made of compacted clay, plastic geomembranes, geosynthetic clay, or other "impermeable" material or of a combination of these materials. Clay barriers are normally required to have a saturated hydraulic conductivity (K) not greater than $1x10^{-7}$ cm/sec; therefore, by definition they are not impermeable. Barrier layers (sometimes called "liners") are more completely described in Koerner and Daniel (1997).
- **RCRA Subtitle D Covers.** These covers consist of two soil layers, including (from the surface downward) a grass cover, topsoil layer, and a layer of soil that is compacted to yield a 10^{-5} cm/sec K value (Ankeny, et al., 1997, and Warren et al., 1997). This cover is less expensive than typical barrier covers and has sometimes been approved by regulators for use in dry climates. However, it generally does not ensure long-term protection against infiltration of precipitation into the waste because freeze-thaw action and root activity are likely to increase the K value of the compacted soil over time.

2.2 Alternative Landfill Covers and Cover Components

Alternative landfill covers are listed below. They are not widely used, and some are still experimental concepts:

- **Capillary Barrier.** The capillary barrier is a component that may be used within other complete covers. It consists of a series of layers, including (from the surface downward) a layer of fine soil over a layer of coarser material (e.g., sand or gravel). The barrier is created in this type of cover by the large change in pore sizes between the layers of fine and coarse material (Stormont, 1997; Gee and Ward, 1997; and Ankeny et al., 1997). Capillary force causes the layer of fine soil overlying the coarser material to hold more water than if there were no change in particle size between the layers. However, this type of barrier can fail if too much water accumulates in the fine-particle layer thus allowing release of water into the coarser layer beneath it. This type of barrier will be breached under these conditions. Lateral drainage, evaporation, and/or plant transpiration remove water stored in the soil above a capillary barrier. This type of barrier has been used in experimental installations.

- **Dry Barrier.** The dry barrier is a component that may be used within other complete covers. It is sometimes called the convective air-dried barrier, and it is similar to the capillary barrier cover except that wind-driven air flow through the layer of coarse material helps to remove water that may infiltrate this layer (Ankeny et al., 1997). Dry barriers may be suitable for landfills in hot, arid climates. They are primarily experimental systems.

- **Asphalt Barrier.** The asphalt barrier is also a component of a complete cover. It may replace the compacted clay layer in covers built in arid climates where a clay barrier may fail because of desiccation (Gee and Ward, 1997). It is a costly, experimental alternative barrier layer that may be useful in special situations.

- **Evapotranspiration (ET) Cover.** The ET cover consists of a layer of soil covered by native grasses; it is a complete cover system. The soil contains no barrier or impermeable layers and uses two natural processes to control infiltration: (1) uncompacted soil provides a water reservoir and (2) natural ET empties the soil water reservoir (Hauser et al., 1995; and Hauser et al., 1996). The soil cover must be correctly designed to store all of the precipitation that infiltrates into the soil until the ET process can remove it. The ET cover is a relatively inexpensive, practical, and easily maintained natural system that will remain effective over extended periods of time—perhaps centuries—at low cost. The technology has been extensively tested. Experimental verification is contained in the work of Anderson et al. (1993), Hauser and Chichester (1989), Nyhan et al. (1990), and Waugh et al. (1994). Long-term verification of the concept over periods of decades and estimates for centuries are found in Cole and Mathews (1939), Aronovici (1971), Sala et al. (1992), Ferguson and Bateridge (1982), Halvorson and Black (1974), Doering and Sandoval (1976), Luken (1962), and Worcester et al. (1975). Although the concept is proven and somewhat similar covers have been built, no ET covers with adequate designs—which would optimally address all of the essential variables of soils, plants, and climate—are known to exist at the date of this report. Hauser et al. (1994) published estimates of the effectiveness of the ET cover at 27 Continental United States (CONUS) sites and found that it should prevent water movement into landfill waste west of Arkansas and can minimize infiltration at numerous landfills in much of the rest of the country.

3 Scope of the Landfill Survey

The data collected in the database were derived from two sources: the Environmental Resources Program Information Management System (ERPIMS) database and a landfill survey designed for this investigation.

3.1 Sources of Data

3.1.1 The ERPIMS Database

ERPIMS is a relational database that serves as the Air Force's repository of environmental investigation and remediation data. The system was known as IRPIMS (Installation Restoration Program Information Management System) until October 1997, when the data model was expanded to cover remediation systems operation and performance.

ERPIMS does not contain all of the information included in the AFCEE landfill survey. However, ERPIMS does provide the number of landfills present on Air Force installations.

3.1.2 The AFCEE Survey

The data were collected on a survey form designed specifically for this report. The form included space for data that were needed to describe Air Force landfills and data that were believed to be available at Air Force bases. Two groups of data were collected and recorded on the survey forms:

- Data about the base or installation as a whole (e.g., location and climate)
- Data specific to each landfill (e.g., contamination, waste found in the landfill, groundwater elevation, and surface area)

Appendix A presents a facsimile of the form used to record data for entry into the database.

3.2 Survey Design

A number of factors are important to landfill remediation. Because data were not available for all potential factors, we chose to include in the survey those data that were both important and readily available from most base records. The following discussion provides an overview of the important factors chosen for inclusion in the AFCEE landfill survey. Appendix A contains the factors included in the survey.

3.2.1 Climate

Precipitation, solar radiation, temperature, and wind are the primary climatic factors that affect landfill remediation. The daily depth of water evaporated from a metal pan at weather stations is recorded as "pan evaporation;" class A pans are the weather bureau's standard measurement device. Pan evaporation integrates the effects of solar radiation, air temperature, relative humidity, and wind; it is also an index of potential evaporation. Therefore, both annual precipitation and annual Class-A pan evaporation were included in the survey data. The ratio of potential evaporation divided by precipitation indicates the likelihood that alternative covers that rely on evaporation will work at a site. This ratio may also indicate the relative probability that precipitation moved through the waste to contaminate groundwater before remediation was initiated.

When precipitation and evaporation data were missing from a completed form, the data were estimated from maps of average annual precipitation and Class-A pan evaporation published by the U.S. Weather Bureau.

3.2.2 Bottom Liners

An impermeable bottom liner is required to be in place under a modern landfill. This type of liner captures leachate from the waste and prevents its migration to groundwater. A bottom liner, if present, may result in the need for a leachate collection and treatment system. Because almost all Air Force landfills were built before the advent of modern rules and regulations, only 1 of the 229 Air Force landfills surveyed has a bottom liner. Therefore, the question of liners will generally have little impact on decisions for the remediation of Air Force landfills.

3.2.3 Depth to Water Table

The greater the distance between the bottom of an unlined landfill and the water table, the lower the probability that leachate contamination from the landfill has reached or will reach the water table. Soil and other geologic material tend to stop or retard the movement of contaminants through absorption/adsorption, natural bioremediation, chemical reactions, and resistance to water movement. Where waste is in contact with groundwater, special care must be exercised in evaluating potential risk and, if needed, in selecting a cover and/or other remediation methods.

3.2.4 Type of Waste

Most Air Force landfills surveyed were primarily designed and operated to receive municipal solid wastes, and most bases operated separate construction and rubble fill sites. Air Force landfills may contain relatively small quantities of paint, heavy metals, pesticides, petroleum products, and cleaning agents. Few, if any, landfills contain significant quantities of radioactive waste.

3.2.5 Groundwater Contamination

Where contaminants have already leached from the landfill and are found in the groundwater, separate groundwater treatment systems may be required in addition to the landfill cover. Depending upon the waste type and the soil and groundwater characteristics, remediation may employ natural attenuation, hydraulic control, treatment walls, or other methods.

3.2.6 Landfill Gas Production

Natural decay of wastes and volatilization of volatile wastes in a landfill may produce sufficient landfill gas to warrant installation of a gas control system under the cover. Gas control systems may be either passive (natural flow) or active (using pumps). Any cover that employs a barrier layer is likely to require an expensive gas control system because the barrier will typically trap the gas produced and, even at low production rates, may accumulate dangerous volumes of explosive and/or poisonous gas.

3.2.7 Soils

An accurate database of information about the soils on and near the base is particularly valuable for evaluating the feasibility of some alternative covers. It is important to know about locally available clays, sands, and other materials that may be required to construct covers. Soil is heavy and thus costly to haul for more than a mile or two, so the availability of suitable soils near a landfill should be considered before selecting a cover type for the landfill.

A convenient source of information about local soils is important in the selection of some of the alternative covers. The U.S. Department of Agriculture (USDA) soil survey is one such source. Availability of soils data was secured from a list published by the Natural Resources Conservation Service–National Soil Survey Center, USDA; this list was last updated in January 1998. The survey is available on the web at www.statlab.iastate.edu/soils/soildiv/sslists/sslisthome.html

4 Results

4.1 Response

Twenty-six Air Force installations returned survey forms, and Mitretek personnel completed surveys for 20 closure bases serviced by AFCEE. Appendix B contains the number of landfills recorded for each base found in either the ERPIMS database or the survey database. The data in Appendix B are grouped by Air Force major command (MAJCOM). MAJCOMs for which survey forms were completed for more than one base include Air Education and Training Command (AETC), Air Mobility Command (AMC), Air Force Material Command (AFMC), Air Force Space Command (AFSPC), Air Force Base Conversion Agency (AFBCA), and Direct Reporting Unit (DRU). MAJCOMs for which no survey forms were completed include Air Combat Command (ACC), Air Force Reserve (AFRES), and Air National Guard (ANG).

4.2 The AFCEE Landfill Survey Database

A database was created using Microsoft Access for Windows 95 (Version 7.0). The database must be read or modified by Access Version 7.0 or a later version. The data are stored in a compressed (zipped) file named “AFCEE Landfill Survey.exe,” (referred to in this report as “the AFCEE landfill survey”). It is a self-extracting zip file that occupies about 405 KB of disk space. Instructions for opening, reading, modifying, and adding to the data file are presented in Appendix C.

Most of the information was entered as it was received on the completed forms. However, reported annual precipitation and pan evaporation values were checked against published maps to ensure accuracy. The survey form (Appendix A) requested 41 separate items of information, but not all of the requested data were available for every landfill. Mitretek Systems added the Class A pan coefficient (plate 3, Kohler et al., 1959) for each base. The product of pan coefficient and pan evaporation provides an estimate of potential annual evaporation for a site.

The ERPIMS database lists 563 landfills on CONUS AFBs (Appendix B). Numbers of landfills for each base were included from ERPIMS in Appendix B; however, no data from ERPIMS were entered into the AFCEE landfill survey database. Figure 1 shows the locations of major CONUS AFBs and indicates those that were included in the AFCEE landfill survey.

4.3 Data and Analysis

The AFCEE landfill survey includes records from 46 bases that contain a total of 229 landfills. This sampling represents about 41 percent of the CONUS Air Force landfills. Characterization of the 229 landfills included in the AFCEE landfill survey is shown in Table 1. Landfills containing wastes that are below the water table pose a special problem and may be costly to remediate.

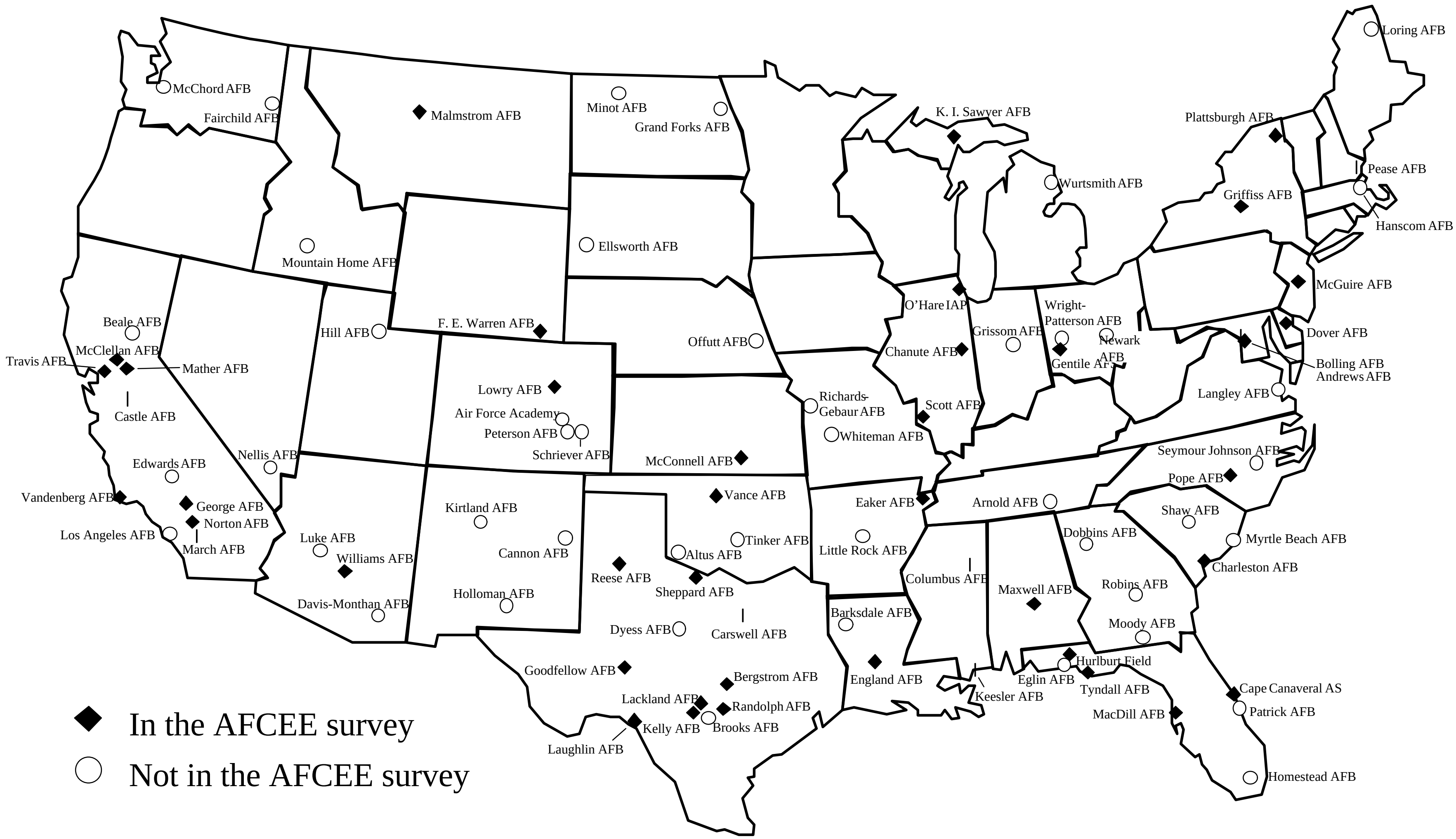

Figure 1. Location of Major Air Force Bases in the Continental U.S. and Those That Were Included in the AFCEE Landfill Survey

Table 1. Characteristics of Landfills Described in the AFCEE Landfill Survey

Characteristic	Percentage
Remediation complete (based on surface area)	23
Inactive (based on number of landfills)	>99
Waste below the water table (based on number of landfills)	20
Landfills with bottom liners (based on number of landfills)	<1

4.3.1 Landfill Dormancy

The landfill survey data indicate that 227 of the 229 landfills are currently inactive. The survey reported years of inactivity or dormancy for 205 landfills. Figure 2 shows the distribution of years of dormancy for the inactive landfills. About 86 percent of Air Force landfills were inactive for more than 20 years before 1999. The period of dormancy of Air Force landfills is significant because it is reasonable to believe that wastes have already decayed significantly in most Air Force landfills and that there is little threat to human health and the environment. Therefore, no further action or a less costly alternative to the conventional covers may be appropriate at many sites.

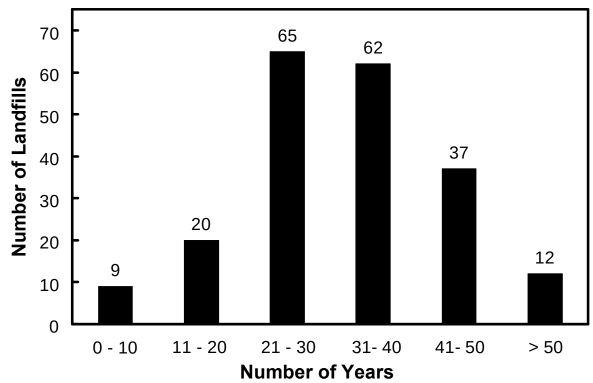

Figure 2. Distribution of the Number of Years that the Surveyed Landfills Were Dormant

4.3.2 Gas Production

Figure 3 shows a typical rate-of-gas production curve under conditions sufficiently wet to permit high decay rates. The rate at which the biodegradation of municipal waste generates gas increases for the first 5 or 6 years after placement in a landfill, and declines thereafter. The rate of gas production depends on many factors; for example, Tchobanoglous and O'Leary (1994) state that the optimum moisture content for decay of waste and the resulting gas production is between 45 and 60 percent. McBean et al. (1995) used results

Figure 3. Typical Rate of Landfill Gas Production

of typical field studies to show that, after 15 years, between 60 and 85 percent of the potential methane production from landfill waste has already been produced. Before a cover is constructed, the waste in a typical Air Force landfill is likely to remain wet and decay rapidly because the temporary covers that are commonly used allow part of the precipitation to pass through the cover and into the waste.

Figures 2 and 3 are significant to landfill remediation and cost at Air Force installations for the following reasons:

- Most Air Force landfills are old and therefore likely to produce only small amounts of landfill gas after cover placement because much—perhaps most—of the decay and concomitant gas production occurred before remediation.
- The placement of a cover will inherently reduce the rate of gas production because the intent of the cover is to stop water from moving into the waste; thus, biological activity will gradually dry the waste.
- The use of alternative covers without gas controls may be a viable alternative and has the potential advantage of reducing both intermediate and long-term remediation costs.

4.3.3 Landfill Surface Area

The cost of placing covers on landfills is directly related to the surface area of the landfill. Surface area data are available for 194 landfills in the AFCEE landfill survey; Figure 4 shows the distribution of areas. The average surface area was 13.3 acres. The total surface area of the 194 landfills is 2,589 acres, and landfills of at least 10 acres account for 87 percent of the total area. Landfills of less than 5 acres account for only 5 percent of the total area; however, they represent 37 percent of the total number of landfills.

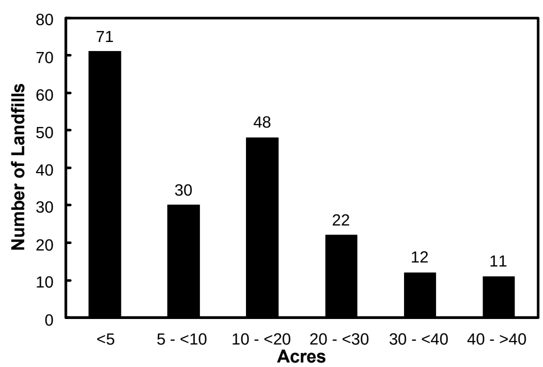

Figure 4. Distribution of Landfill Surface Area for 194 Landfills

4.3.4 Evaporation Ratio and Its Influence on Remediation

Alternative covers such as the capillary barrier, dry barrier, and ET cover depend on both evaporation and plant transpiration (ET) to remove water from the cover and thus to achieve landfill remediation goals (AFCEE, 1999). The ET process may also influence need for or performance of groundwater remediation.

Numerous variables interact in complex ways to control the ET process, including solar radiation, air temperature, humidity, wind, and plant and soil properties. It is beyond the scope of this work to fully evaluate each of these parameters for sites shown in the AFCEE landfill survey. However, class-A pan evaporation data are available in the survey data for each base and represent the integrated interactions and effects of these variables on the hydrologic system. Evaporation from a shallow lake is similar to the water loss from a well-watered grass cover; therefore, it is a good estimate of potential ET. Kohler et al. (1959) derived methods for converting weather bureau, class A pan evaporation to shallow lake evaporation. Mitretek used their method to compute an estimate of potential ET at each of the 46 Air Force bases for which data are available in the AFCEE landfill survey. First, we estimated lake evaporation by using measured class A pan evaporation data and the pan coefficient read from the maps published by Kohler et al. (1959):

Lake evaporation = Class A Pan Evaporation x Pan Coefficient

The evaporation ratio is defined as follows:

Ratio = Annual Lake Evaporation / Annual Precipitation

Therefore, this evaporation ratio is a satisfactory estimate of the ratio of potential ET and annual precipitation.

Figure 5 shows the distribution of the evaporation ratio for all Air Force bases included in the AFCEE landfill survey, and the data are shown in Appendix D.

Where the evaporation ratio is greater than one, groundwater recharge from precipitation may be relatively low. In these situations, potential groundwater contamination by landfill wastes may be of less concern than in cold, humid regions where the ratio is less than one.

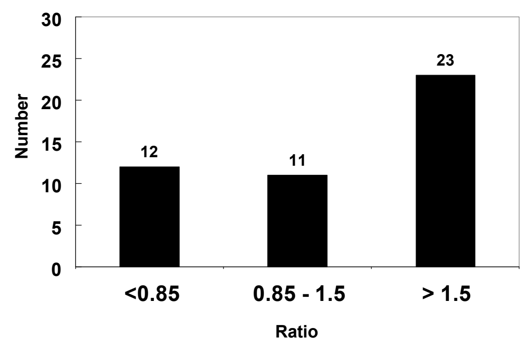

Figure 5. Evaporation Ratio at 46 Air Force Bases

Success of some alternative landfill covers—such as the ET cover—depends upon removal of water from the cover by ET. Where potential ET is equal to or greater than annual precipitation (ratio > 1.0), ET may remove all infiltrating water. ET covers built in these regions are likely to meet requirements for the cover. Where the evaporation ratio is less than 1.0, the ET cover may meet requirements for a cover if sufficient precipitation is lost as surface runoff; this is the probable case at many locations, particularly those with ratios near 1.0.

Half of the surveyed bases have ratios greater than 1.5; thus, ET covers should be effective at those bases, and groundwater recharge should be small. Twenty-four percent of the bases have ratios between 0.85 and 1.5, and ET covers should be effective at many, but not all, sites in this group. The remaining 26 percent of the bases have low evaporation ratios, and some of them are in cold climates with short growing seasons; therefore, a smaller number of them will be candidates for the ET cover, and groundwater recharge is likely to be relatively large.

4.3.5 No Further Action

The NFA alternative was adopted for 12 percent of the landfills in the AFCEE landfill survey. The evaporation ratio data show that groundwater recharge should be small for half of the CONUS Air Force bases. This finding suggests that an NFA decision should be considered for a greater percentage of Air Force landfills than the survey results indicate.

5 Risk-Based/Performance-Based Remediation

The survey results may be used in conjunction with the risk-based/performance-based (RB/PB) landfill remediation decision process to improve the quality of remediation and often to significantly reduce costs. This section presents a summary of the process and examples of its use. The RB/PB process is discussed in greater detail in AFCEE (1999).

RB/PB landfill remediation is a scientifically based approach for selecting protective remediation options based on the specific conditions at a landfill. Using RB/PB selection of remediation alternatives will allow landfill owners to determine the specific technical performance requirements of a remediation plan that addresses the site-specific risks at a landfill. After these technical performance requirements are determined and accepted by the public and regulatory community, any particular landfill remediation scenario that meets the requirements—including alternative or innovative covers—can be selected.

5.1 Selection Process

The RB/BP landfill remediation selection process follows four well-defined steps that are routinely used in environmental risk assessments:

1. Based on known waste materials and environmental sampling, determine the ***releases*** associated with a particular landfill, including the following:
   - Surface debris
   - Gas generation
   - Leachate production
   - Groundwater and surface water contamination
2. Determine the ***pathways*** of exposure to potential receptors, including the following:
   - Direct contact
   - Airborne emissions
   - Water contamination
3. Determine the ***risks*** associated with each source–pathway–receptor combination.
4. Determine the specific ***performance requirements*** of each action that must be taken to address the identified risks, including the following:
   - No-further-action if no significant risks were identified
   - Cover requirements to eliminate direct contact
   - Cover requirements to limit infiltration and thus to limit leachate generation
   - Gas collection and/or treatment requirements, if any
   - Requirements for remediating groundwater or surface water contamination

5.2 Application

After a performance requirement has been established for a particular remedial action, any remedial alternative meeting that requirement can be selected and applied at that landfill. This process eliminates the need to follow the classic ARARs approach to determine remediation requirements. It also allows the Air Force to select the most technically sound and cost-effective alternative to address the risk at a particular landfill.

The following examples of the RB/PB landfill remediation approach illustrate the advantages of the concept.

- A 10-acre landfill has not been used for 15 years, but it is known to contain drums of trichloroethylene (TCE) and some arsenic. The landfill has no liner and the water table is 30 feet below the waste. Petroleum products and TCE were found in the groundwater near the landfill. There is evidence that natural attenuation is containing the groundwater plume and that the plume has ceased to advance. Because serious groundwater contamination could occur if large amounts of TCE or arsenic leached from the waste, this landfill requires a cover that minimizes infiltration. Therefore, this base should construct either a conventional or alternative cover designed to minimize infiltration for the climate at the site. Because of the existing groundwater plume and the future threat of contamination, groundwater monitoring must continue.

- A 10-acre landfill has not received waste for 30 years. Groundwater and surface soil samples have found no contamination above maximum contaminant levels (MCLs) or preliminary remediation goals (PRGs), and there is no evidence of significant gas production. Traditionally, a RCRA Subtitle D or other soil cover and groundwater monitoring would be recommended for this landfill. The RB/PB criteria found no contaminant releases and no risk. Therefore, a no-further-action decision is fully warranted.

6 Cost Comparison Example for Conventional and Alternative Landfill Covers

This section provides an evaluation of construction costs associated with both conventional and alternative landfill covers. The conventional covers used for comparison were barrier-type, RCRA covers. The capillary barrier, dry barrier, and asphalt barrier are alternative barriers that may be used within other landfill cover systems. They appear to have limited usefulness for Air Force landfill covers. The ET cover for landfills is a complete cover, and the concept has been verified, as stated elsewhere in this report.

The discussion focuses on conventional RCRA covers and the ET cover because cost data were most readily available for these approaches. These analyses demonstrate the potential value that may be derived from use of the RB/PB approach and alternative landfill covers.

6.1 Cost Data

Cost data contained in the AFCEE landfill survey reveal that costs for conventional covers constructed at Chanute, Keesler, Lackland, and Pease AFBs range from $319,000 to $571,000 per acre of landfill (Table 2). The AFCEE landfill survey contains no cost data for alternative covers.

The Air Force obtained fully developed construction cost estimates for both a conventional and an ET cover for Landfill 6 at F. E. Warren AFB (Table 3). Both cost estimates were based on complete cover designs for the site. A cost estimate for the ET cover

Table 2. Costs for Completed, Conventional Landfill Covers Contained in the AFCEE Landfill Survey

Base	Landfill Number	Area (Acres)	Cost	Cost per Acre	Cover Type
Chanute	LF-1	19	$8,363,407	$440,179	RCRA Cover
	LF-2	20	$9,014,113	$450,706	RCRA Cover
	LF-3	17	$7,661,996	$450,706	RCRA Cover
	LF-4	15	$6,760,584	$450,706	RCRA Cover
Keesler	LF-3	10	$5,000,000	$500,000	Clay barrier
Lackland	LF028	20	$8,000,000	$400,000	Clay and Membrane Barrier
	LF029	7	$4,000,000	$571,429	Clay and Membrane Barrier
Pease	LF 5	30	$9,559,071	$318,636	Clay and Membrane Barrier

Table 3. Cost Comparison of Landfill Covers for Landfill 6 at F. E. Warren AFB

Cover Type	Cost ($/Acre)	Savings with ET cover ($/Acre)
ET cover (U.S. Air Force, 1997)	$147,600	-------------
Geosynthetic barrier (U.S. Air Force, 1996)	$359,500	$211,900
Compacted clay and membrane barrier (Air Force slides)	$395,000	$247,400

is contained in U.S. Air Force (1997), and a cost estimate for a conventional geosynthetic barrier cover can be found in U.S. Air Force (1996). Estimates for a conventional cover, including both compacted clay and geomembrane barriers, for Landfill 6 are also available from an Air Force slide presentation.

The cost estimates for both of the conventional covers on Landfill 6 (Table 3) were consistent with or lower than the costs reported in the AFCEE landfill survey (Table 2). The estimates suggest that the cost savings resulting from using the ET cover on Landfill 6 could be in the range of $200,000 to $250,000 per acre.

6.2 Cost Savings Estimates

An estimate follows of potential cost savings to the Air Force resulting from using the alternative ET cover instead of the RCRA cover on appropriate landfills. Conservative estimates are used in an effort to produce cost savings estimates that are likely to be met or exceeded during field application.

Past estimates have conservatively estimated construction cost savings from using the ET cover at $150,000 per acre of cover (Hauser and Weand, 1998). This conservative figure equates to only 70 percent of the smallest cost savings estimated for Landfill 6 at F.E. Warren AFB (Table 3). An estimate based on the actual data from F.E. Warren AFB indicates that savings could well exceed $200,000 per acre (Table 3).

Appendix E presents the area of landfills at each base in the AFCEE landfill survey for which the area is known and indicates whether remediation is complete or incomplete. Area data were missing for 35 landfills in the AFCEE landfill survey.

Table 4 presents an estimate of the total area for which the ET cover is the appropriate choice among the landfill data contained in the AFCEE landfill survey.

It is unlikely that the ET cover is appropriate for all sites. The landfills in the AFCEE survey that were not remediated were divided into three groups (Appendix E). The first group included landfills at bases where the evaporation ratio exceeds 1.5. The potential ET is substantially higher than the annual precipitation for this group of landfills, and all of the 971 acres of landfill surface in this group are candidates for the ET cover (Table 4).

Table 4. Minimum and the Likely Area of Landfills in the AFCEE Landfill Survey for which the ET Cover is a Suitable Alternative to the RCRA Cover and Which are Not Remediated

Suitability of ET cover	Ratio[1]	Min.[2] Acres	Likely[3] Acres
All suitable for ET cover	>1.5	971	971
Site-specific, 25% or 60% suitable	0.85 – 1.5	163	391
ET cover assumed inappropriate	< 0.85	0	0
	Total =	**1,134**	**1,362**

[1]Ratio of annual evaporation/annual precipitation
[2]Minimum acres that are not remediated and for which the ET cover is effective
[3]Likely acres for which the ET cover is effective and are not remediated

The second group included bases where the evaporation ratio fell between 0.85 and 1.5 (Appendix E). Because the ratio is near 1.0, surface runoff will play an important role in determining the success of an ET cover. We estimated that at least 25 percent and up to 60 percent is a likely fraction of the 652 acres of landfill surface in this group for which the ET cover could meet the requirements for a cover (Table 4).

The third group included bases where the evaporation ratio fell below 0.85 (Appendix E). Although the ET cover is likely to meet the requirements for some of these bases it was conservatively assumed that the ET cover is inappropriate for the entire 382 acres in this category (Table 4).

The total area of landfill surface that is reported in the AFCEE landfill survey is 2,589 acres. The data in Table 4 suggest that at least 44 percent (1,134 acres) and up to 53 percent (1,362 acres) of all Air Force landfill area is appropriate for the ET cover.

6.3 Potential Cost Savings: RCRA Cover vs. ET Cover

Mitretek estimated possible savings to the Air Force from the use of the ET cover based upon the data contained in the AFCEE landfill survey and the cost figures stated above. The ERPIMS database records 563 CONUS landfills (Appendix B). Therefore, assuming that the average landfill area is 13.3 acres, the Air Force is responsible for about 7,490 acres of CONUS landfills. As shown above, estimates from the landfill survey revealed that at least 44 percent and up to 53 percent of Air Force landfills are not remediated but are suitable for the ET cover. Using the cost savings factors (a RCRA cover versus an ET cover), as calculated above, of at least $150,000 and possibly exceeding $200,000 per acre of surface in construction cost, the potential cost savings are calculated as follows:

- ET cover savings, assuming 44 percent compatible acreage at $150,000/acre:

  7,490 acres x 0.44 x $150,000/acre = $494,340,000

- ET cover savings, assuming 53 percent compatible acreage at $200,000/acre:

  7,490 acres x 0.53 x $200,000/acre = $793,940,000

Thus, even in a very conservative scenario, the potential construction cost savings is about $500 million and could exceed $750 million. The use of the RB/PB approach may allow the ET cover to be used on a significant number of landfills. This offers one example of how the RB/PB approach to landfill assessment can be used to realize the potential for cost savings resulting from using alternative remediation methods. The discussion in this report is also an example of the importance of planning and the power provided by landfill inventory data.

List of References

AFCEE. 1999. *Landfill Covers for Use at Air Force Installations.* Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, TX.

Anderson, J. E., R. S. Nowak, T. D. Ratzlaff, and O. D. Markham. 1993. *Managing soil moisture on waste burial sites in arid regions.* J. Environ. Qual. 22:62-69

Ankeny, M. D., L. M. Coons, N. Majumdar, J. Kelsey, and M. Miller. 1997. *Performance and Cost Considerations for Landfill Caps in Semi-Arid Climates.* In: Reynolds, T. D., and R. C. Morris (eds.), Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions, Environmental Science and Research Foundation, Idaho Falls, ID.

Aronovici, V. S. 1971. *Percolation of water through Pullman soils, Texas High Plains*, B-1110. The Texas Agric. Exp. Sta., College Station, TX.

Cole, J. S., and O. R. Mathews. 1939. *Subsoil moisture under semiarid conditions.* Technical Bulletin 637, U.S. Department of Agriculture.

Doering, E. J., and F. M. Sandoval. 1976. *Hydrology of saline seeps in the northern great plains*. Trans. ASAE 19(5): 856-861 & 865.

Ferguson, H., and T. Bateridge. 1982. *Salt status of glacial till soils of north-central Montana as affected by the crop-fallow system of dryland farming*. Soil Sci. Soc. Am. J. 46:807-810.

Gee, G. W., and A. L. Ward. 1997. *Still in Quest of the Perfect Cap.* In: Reynolds, T. D., and R. C. Morris (eds.), Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions, Environmental Science and Research Foundation, Idaho Falls, ID.

Halvorson, A. D., and A. L. Black. 1974. *Saline-seep development in dryland soils of northeastern Montana.* J. Soil and Water Conservation 29:77-81.

Hauser, V. L., and B. L. Weand. 1998. *Natural Landfill Covers.* Presented at the Third Tri-Service Environmental Technology Workshop, San Diego, CA 18-20 August.

Hauser, V. L., and F. W. Chichester. 1989. *Water relationships of claypan and constructed soil profiles.* Soil Sci. Soc. of Am. J., 53(4): 1189–1196.

Hauser, V. L., M. A. Shaw, and B. L. Weand. 1994 *Effectiveness of Soil-Vegetative Covers for Waste Sites.* Proceedings Superfund XV, Nov. 29-Dec. 1, Superfund XV, Rockville, MD.

Hauser, V. L., M. A. Shaw, and B. L. Weand. 1995. *A Natural Cover for Buried Waste.* Proceedings, American Defense Preparedness Association, Arlington, VA.

Hauser, V. L., B. L. Weand, M. A. Shaw, and A. R. Wusterbarth. 1996. *Natural Covers for Landfills A Closer Look.* Proceedings, American Defense Preparedness Association, Arlington, VA.

Kohler, M. A., T. J. Nordenson, and D. R. Baker. 1959. *Evaporation maps for the United States.* U.S. Department of Commerce, Weather Bureau, Tech. Paper no. 37.

Koerner, R. M., and D. E. Daniel. 1997. *Final Covers for Solid Waste Landfills and Abandoned Dumps*. American Society of Civil Engineers, Reston, VA.

Luken, H. 1962. *Saline soils under dryland agriculture in southeastern Saskatchewan (Canada) and possibilities for their improvement*. Plant and Soil 17:1-25.

McBean, E. A., F. A. Rovers, and G. J. Farquhar. 1995. *Solid Waste Landfill Engineering and Design.* Prentice Hall, 521 pp.

Nyhan, J. W., T. E. Hakonson, and B. J. Drennon. 1990. *A water balance study of two landfill cover designs for semiarid regions*. J. Environ. Qual. 19:281-288.

Sala, O. E., W. K. Lauenroth, and W. J. Parton. 1992. *Long-Term Soil Water Dynamics in the Shortgrass Steppe.* Ecology, 73(4): 1175-1181.

Stormont, J. C. 1997. *Incorporating Capillary Barriers in Surface Cover Systems*. In: Reynolds, T. D. , and R. C. Morris (eds.), Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions, Environmental Science and Research Foundation, Idaho Falls, ID.

Tchobanoglous, G., and P. R. O'Leary. 1994. *Landfilling.* Chapter 12 in Kreith, F. (ed.), Handbook of Solid Waste Management. McGraw-Hill.

U. S. Air Force. 1996. *Multi-Layer Cap Cost Estimate for Landfill 6.* F. E. Warren AFB, Cheyenne, WY.

U. S. Air Force. 1997. *Interim Remedial Action, Landfill 6 Source Control, Vol. 2 of 4, Final Cost Estimate.* F. E. Warren AFB, Cheyenne, WY.

Warren, R. W., T. E. Hakonson, and K. V. Bostik. 1997. *The Hydrologic Evaluation of Four Cover Designs for Hazardous Waste Landfills.* In: Reynolds, T. D., and R. C. Morris (eds.), Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions. Environmental Science and Research Foundation, Idaho Falls, ID.

Waugh, W. J., M. E. Thiede, D. J. Bates, L. L. Cadwell, G. W. Gee, and C. J. Kemp. 1994. *Plant cover and water balance in gravel admixtures at an arid waste-burial site.* J. Environ. Qual. 23:676-685.

Worcester, B. K., L. J. Brun, and E. J. Doering. 1975. *Classification and management of saline seeps in western North Dakota*. North Dakota Farm Research 33(1):3-7.

Appendix A

Landfill Survey Form

Landfill Survey

Please fill out one form for each landfill (both active and inactive) at your installation. If there are any questions about the survey or how to fill it out, please call add number/person here.

Person completing survey Name: Phone:	
Base Name	
MAJCOM	

Part I
Installation Information

Latitude	
Longitude	
State	
County(s)	
Nearest City/Town	

Is there a USDA soil survey of the base?	☐ Yes ☐ No ☐ Do Not Know
Annual Precipitation, inches	
Annual Class-A Pan Evaporation, inches	

Part II
Landfill Information

Official Landfill Name	
Current Status	☐ Active ☐ Inactive
Regulatory Status	☐ NOV ☐ RCRA ☐ CERCLA ☐ NFA (No Further Action) ☐ Other Specify:
Status of Cleanup/Closure Process (check all that apply)	☐ ROD ☐ RI/FS ☐ Construction Plans ☐ Remediation Under Way ☐ Other Specify:
Current Programmed Method for Remediation:	☐ Not Selected ☐ Clay Barrier ☐ Flexible Membrane Barrier ☐ Clay and Membrane Barrier ☐ Soil Cover ☐ Evapotranspiration (ET) Cover ☐ Removal (Dig & Haul) ☐ Other Specify:
Gas Control?	☐ Yes ☐ No
Approximate Cost	
Dates of Operation: Year Operations Began: Year Operations Ended: Other relevant operational dates (if any):	
Landfill Surface Area, acres	
Maximum Depth of Landfill, feet	
Landfill Type	☐ Pit ☐ Trench ☐ Other Specify:
Types of Waste Contained (Check all that apply.)	☐ Asbestos ☐ Construction ☐ Household ☐ Heavy Metals ☐ Paint ☐ Pesticides ☐ Petroleum Products ☐ Radioactive ☐ Rubble ☐ Solvents ☐ Other Specify:

<table>
<tr><td>Waste Above Water Table?</td><td>☐ Yes ☐ No</td></tr>
<tr><td>Depth from Land Surface to Uppermost Aquifer Beneath Landfill, feet</td><td></td></tr>
<tr><td>Geologic Formation Under Landfill</td><td></td></tr>
<tr><td>Vertical Permeability of Formation under Landfill</td><td>☐ High ☐ Moderate ☐ Low
K (if known):
Describe if necessary:</td></tr>
<tr><td colspan="2">Does the landfill have a bottom liner? ☐ Yes ☐ No
If yes- Liner Material(s):
Liner Thickness, feet:
Additional Description (if necessary):</td></tr>
<tr><td colspan="2">Current Cover:
Thickness, feet:
Soil Type:
Vegetation: ☐ Grass ☐ Trees ☐ Brush
☐ Other Specify:</td></tr>
<tr><td colspan="2">Specific Contaminants Reported:
In Landfill:

In Groundwater:

In Soil (if applicable):</td></tr>
<tr><td colspan="2">Community Perception/Involvement:
Briefly, what is the communities perception of the installation and its remediation program. Does it support current efforts? Do they stay involved?</td></tr>
<tr><td colspan="2">Source(s) of Information:
Please list the sources used to fill out this survey.</td></tr>
</table>

Appendix B

Number of Air Force Landfills within the Continental United States Contained in ERPIMS or the AFCEE Landfill Survey

Major Command/Installation Name	State	Landfills in ERPIMS[1]	Landfills in Survey[2]
Air Education and Training Command (AETC)			
Altus	OK	3	---
Columbus	MS	8	8
Goodfellow	TX	2	2
Gunter Annex	AL	1	---
Keesler	MS	3	3
Lackland	TX	5	5
Laughlin	TX	1	1
Little Rock	AR	7	---
Luke	AZ	7	---
Maxwell	AL	3	6
Randolph	TX	1	5
Sheppard	TX	3	3
Tyndall	FL	6	13
Vance	OK	3	1
Command Total		**53**	**47**

Air Mobility Command (AMC)			
Andrews	MD	3	1
Charleston	SC	4	1
Dover	DE	12	5
Fairchild	WA	2	---
Grand Forks	ND	3	---
MacDill	FL	19	2
McChord	WA	9	---
McConnell	KS	4	7
McGuire	NJ	6	6
Pope	NC	10	9
Scott	IL	1	1
Travis	CA	4	4
Command Total		**77**	**36**

Major Command/Installation Name	State	Landfills in ERPIMS[1]	Survey[2]
Air Force Materiel Command (AFMC)			
AFP PJKS Waterton	CO	1	---
AFP 3–Tulsa	OK	1	---
AFP 4–Ft Worth	TX	4	---
AFP 42–Palmdale	CA	1	---
AFP 44–Tucson	AZ	2	---
AFP 6–Marietta	GA	2	---
Arnold	TN	3	---
Brooks	TX	6	---
Edwards	CA	7	---
Eglin	FL	32	---
Hanscom	MA	3	---
Hill	UT	7	---
Kelly	TX	8	13
Kirtland	NM	14	---
Los Angeles	CA	0	---
McClellan	CA	0	18
Robins	GA	6	---
Tinker	OK	6	---
Wright-Patterson	OH	26	---
Command Total		**129**	**31**

Air Force Space Command (AFSPC)			
Cape Canaveral Air Station	FL	2	2
F E Warren	WY	6	6
Malmstrom	MT	2	1
New Boston Air Station	NH	1	---
Patrick	FL	5	---
Peterson	CO	3	---
Vandenberg	CA	20	4
Command Total		**39**	**13**

Major Command/Installation Name	State	Landfills in ERPIMS[1]	Landfills in Survey[2]
Air Force Base Conversion Agency (AFBCA)			
Bergstrom	TX	7	7
Carswell	TX	6	11
Castle	CA	13	7
Chanute	IL	4	4
Eaker (Blytheville)	AR	4	5
England	LA	13	5
Gentile Air Station	OH	3	1
George	CA	18	14
Griffiss	NY	6	7
Grissom	IN	3	---
Homestead	FL	2	---
K I Sawyer	MI	4	4
Loring	ME	4	---
Lowry	CO	3	2
March	CA	8	6
Mather	CA	6	6
Myrtle Beach	SC	5	---
Newark Air Station	OH	2	---
Norton	CA	2	2
O'Hare International Airport	IL	2	2
Pease	NH	8	4
Plattsburgh	NY	5	4
Reese	TX	3	7
Richards-Gebaur	KS	2	---
Rickenbacker	OH	1	---
Williams	AZ	2	1
Wurtsmith	MI	8	---
Command Total		**144**	**99**

Major Command/Installation Name	State	Landfills in ERPIMS[1]	Landfills in Survey[2]
Direct Reporting Units (DRU)			
Air Force Academy	CO	0	---
Bolling (AFDW)	DC	2	2
Hurlbert Field (AFSOC)	FL	3	1
Command Total		**5**	**3**

Air Combat Command (ACC)			
Barksdale	LA	3	---
Beale	CA	10	---
Cannon	NM	6	---
Davis-Monthan	AZ	2	---
Dyess	TX	2	---
Ellsworth	SD	7	---
Holloman	NM	7	---
Langley	VA	12	---
Minot	ND	1	---
Moody	GA	4	---
Mountain Home	ID	3	---
Nellis	NV	14	---
Offutt	NE	6	---
Seymour-Johnson	NC	6	---
Shaw	SC	3	---
Whiteman	MO	5	---
Command Total		**91**	**0**

Air Force Reserve (AFRES)			
Dobbins	GA	1	---
Minneapolis-St Paul International Airport	MN	2	---
Niagara Falls International Airport	NY	1	---
Westover	MA	2	---
Command Total		**6**	**0**

Major Command/Installation Name	State	Landfills in ERPIMS[1]	Landfills in Survey[2]
Air National Guard (ANG)			---
Buckley	CO	1	---
Burlington	VT	2	---
Hancock Field	NY	3	---
McEntire	SC	3	---
Otis	MA	2	---
Phelps-Collins	MI	1	---
Selfridge	MI	3	---
Stewart	NY	1	---
Volk Field	WI	3	---
Command Total		**19**	**0**
Grand Totals		**563**	**229**

[1] ERPIMS = Environmental Resources Program Information Management System
[2] Survey data from AFCEE Landfill Survey

Appendix C

Using the AFCEE Landfill Survey Database

The database is distributed as a self-extracting, compressed (zipped) file. The file name is **"AFCEE Landfill Survey.exe"** and it occupies about 405 KB on a floppy disk.

To unzip the file, double-click the file name. It may be unzipped from the floppy or from another drive. The software prompts the user to enter the location in which to store the expanded database file and then stores the file at that location as an Access file that is ready for use.

The database was created in Microsoft Access for Windows 95 (also known as Access Version 7.0) and therefore requires Access for Windows 95 or a later version to manipulate the data. These instructions assume the user has basic knowledge of Windows 95 operation and file location procedures.

1.1 Backing Up the AFCEE Landfill Survey Database

Before adding or updating data, it is strongly recommended that the user make a backup copy of the database. The original compressed file can serve as the backup file if it is maintained in its original condition.

1.2 Loading the AFCEE Landfill Survey Database

The database is contained in a file named **AFCEE Landfill Survey.mdb**. It can be run from either a floppy disk or a hard drive. Performance will be better if the database is run from a hard drive. Before running the database from a hard drive, copy it to any folder. Do not attempt to run it from a **write-protected** disk. It will not open properly, and the computer may freeze.

If the database is opened in a Microsoft Access for Windows version later than Windows 95 (Version 7.0), a “Convert/Open Database” dialog will appear. If the database is to be used with Access 95 in the future, the **Open Database** option should be used. Once converted to a newer version, the database will no longer be usable with Access 95. However, some buttons may not work if no conversion is done. If the **Convert Database** option is selected, the user will be prompted for a new name. It is recommended to create the converted database under a different name in case an error occurs during the conversion process.

1.3 Starting the AFCEE Landfill Survey Database

The user may access the database from a hard drive or a disk in three ways:

- Start Microsoft Access. After Access starts, a box may prompt the user to either start a new database or open an existing one. Click **Open an Existing Database**. If AFCEE Landfill Survey.mdb appears in the file list, click it and then click the **OK** button. If AFCEE Landfill Survey.mdb is not in the list, select "**More Files** ," click **OK**, and then use the open file dialog box to navigate to and open AFCEE Landfill Survey.mdb in the same way as for any document or spreadsheet file.
- Start Microsoft Access. If a prompt requesting a file name is not displayed, click **File** in the main menu, and then click **Open Database**. Open the database in the same way as any other document or spreadsheet file.
- Find the file AFCEE Landfill Survey.mdb in a folder and double-click it. This will start Microsoft Access and open the database file.

After the database has opened, an informational form will appear. Press either the space bar or the enter key or click anywhere on the form to proceed. The **Main form** will then open automatically. This form allows the user to do the following:

- Access the **Installation** and **Landfill** forms to view, edit, or enter data
- Preview and print previously designed reports
- Export report content to electronic files

As the user navigates the database, it is possible to return to the **Main form** by clicking the **M** button, located on all of the installation and landfill forms. The forms also contain other buttons to automate commonly executed actions. However, users with Access experience may also use functions available in the menus and toolbars.

The data is organized into two sets of related information: (1) Air Force base or installation data and (2) individual landfill data.

1.4 Viewing Information

1.4.1 To View Installation Data

Click the **Installation** button in the **View** section on the **Main form**. This opens the **Installation** form. All installation-related data are shown in the fields on this form. There are three ways to reach a particular installation's record:

- Use the **Page Up** and **Page Down** keys.
- Click the horizontal right or left arrows on the record selector (horizontal arrows next to the word **Record** at the bottom of the form window).
- Select the desired installation in the **Go To Installation** drop-down box at the top of the form.

With the exception of Remarks, data cannot be entered or edited when viewing landfill data in this form. This restriction is imposed to minimize the possibility of inadvertent changes to the data. See the section below for further instructions on Entering/Editing Installation and Landfill Data.

1.4.2 To Filter Installation Records

If desired, the user can restrict the records available for view by using a filter based on an installation's command, state, and EPA region. Select any combination of MAJCOM, state, and EPA region in the drop-down boxes at the top of the form. Then, click the **Apply Filter** button. Any installation not meeting the criteria will no longer be available. Look at the record selector at the bottom of the window to see how many installations meet the criteria. If *no* installations meet the criteria, the form will become blank. To remove the filter and make all records available again, click the **Show All** button. Working with filters does not affect the data in any way. Setting a filter limits the number of records available for viewing—no data is deleted.

1.4.3 To View Landfill Data

Click the **Landfill** button in the **View** section on the **Main form**. This opens the **Landfill form**. The primary landfill data is shown in the fields on this form. This form exceeds normal screen size, therefore, only part of the data is available for viewing in one screen. Move to the bottom or top of the form by using the scroll bar on the right-hand edge of the screen or the **Page Up** or **Page Down** keys.

There are four ways to move through the landfill records:

- Select the desired installation in the drop-down box located at the top of the form, headed by **Limit List to Landfills from This Base Only**. This will limit the records available to those from the selected installation only. To make all landfill records available again, click **View All**.
- Click the record selector arrows (left and right horizontal arrows next to the word "**Record**" at the bottom of the form window).
- **Page Up** and **Page Down** keys move the cursor through the current record and then to the next record. For example, if the beginning of a record is currently on the screen, the first "page down" will move the view to the lower section of the current record, another "page down" is necessary to move to the next record.
- **Control-Page Down** and **Control-Page Up** will display the next or previous record respectively. The combination of **Control-Page Down** changes the display directly from the top of one record to the top of the next record.

Waste and contaminant data are each displayed on separate forms. To view that data, go to the desired landfill record and click on the **Wastes** or **Contaminants** button.

2.0 Modifying the Data

2.1 Editing Data

The data entry forms must be used to edit previously entered data for installations or landfills. On the **Main form**, click the **Installation** or **Landfill** button in the **Edit/New** section. This will open forms similar to those used for viewing, except these forms allow records to be added and edited. Data can be edited at any time, but *all changes* will be saved when you move to another record. You can also save all changes to a record by clicking the **Save Base** or **Save Landfill** buttons. The user may undo changes by clicking the **Undo Changes** button, *but this* must *be done before a record has been saved*. Keep in mind, any changes that have been saved by either moving to another record or clicking the **Save** button *will not* be undone.

2.2 Entering New Installations and Landfills

To enter new installation or landfill data, open the data entry forms. Every landfill must be related to an installation; therefore, when entering new installations and their landfills, *the installation information must be entered first*.

2.2.1 To Enter a New Installation

Open the **Installation** data entry form by clicking the **Installation** button in the **Edit/New** section on the **Main form**. Click the **New Base** button to obtain a blank form. Use the **New Installation Name** drop-down box to select the name of the new base. When it is selected, the Air Force installation identification code **(AFIID)** and **MAJCOM** boxes will be automatically entered. The AFIID is a unique value used to identify a base or installation within the ERPIMS database. The database contains the names, major commands, and AFIIDs for major Air Force bases and installations.

2.2.2 To Enter a New Landfill

Open the **Landfill** data entry form by clicking the **Landfill** button in the **Edit/New** section on the **Main form**. Then, click the **New Landfill** button.

Each landfill must have a unique identification code. When you attempt to enter a new record, the **Generate ID** form will open to help you generate a new, unique ID code. You can click the **Cancel** button on this form at any time to abandon this procedure.

On the **Generate ID** form, enter the appropriate installation in the **Choose Installation** drop-down box. If the desired installation is not in this drop-down box, it must be entered into the database (see the previous section). After selecting a base, enter one to three characters in the second field. The characters entered should be—but are not required to be—

related to the landfill in some way. For instance, “9” for LF-09, “45” for SWMU 45, or “X” for Landfill X. The ID Generator will construct an ID from the AFIID of the installation and the identifying characters you entered. It will then check the database to ensure that the new Landfill ID is not already in use. If the new Landfill ID is validated, it is displayed to the user. At this point, the user may **commit**; this action will assign the new Landfill ID and the corresponding AFIID to a new record and then save the record. The AFIID is used to relate the landfill to its installation. After the ID is committed, the remaining landfill data can be entered. If for any reason, the user does not wish to commit the ID, click **Cancel** to return to the ID generator. Click **Cancel** again to return to the landfill form.

To enter waste or contaminant data for a landfill, click the **Wastes** or **Contaminants** button and enter the data on the forms provided. The data you enter will be associated with the landfill that is currently displayed on the **Landfill** form.

2.3 Deleting Data

Records may be deleted from either the view or the data entry version of the forms.

2.3.1 To Delete an Installation

If you wish to delete an installation from the database, click the **Delete Base** button in either installation form. *If an installation is deleted, all data pertaining to landfills associated with that base will also be deleted.* This includes waste and contaminant data for each landfill at the installation. If the **Delete Base** button is clicked, the user will be warned and given the opportunity to cancel the deletion. The deletion of a base *cannot* be undone.

2.3.2 To Delete a Landfill

To delete a landfill from the database, open a landfill form (either the view or data entry form) and click the **Delete Landfill** button. *If a landfill is deleted, all waste and contaminant data related to that landfill will also be deleted.* If the **Delete Landfill** button is clicked, the user will be warned and given the opportunity to cancel the deletion. The deletion of a landfill *cannot* be undone.

3.0 Printing

3.1 Printing from Forms

All of the **Installation** and **Landfill** forms have two buttons that allow you to print the form. The appearance of the printed form will be substantially the same as that exhibited on the screen. All the data fields will be printed, but non-data related items such as buttons will not print. Data fields with extensive text will expand in the printed version of the form to show all text.

- Click **Print Record** to print one copy of the record you are currently viewing.
- Click **Print All** to print all currently available records.

For example, if you have restricted (or filtered) the installations shown to only those from a single command, only those records will be printed. If you have *not* filtered—or restricted—the installations shown, the program will print the record of every installation in the database. When using the **Print All** button, you will be given the opportunity to cancel the action. Using the print buttons on the form screen is recommended, because the print commands in the tool bar may print all records, even if a filter is set.

3.2 Printing, Previewing, and Exporting Pre-Designed Reports

Selected, pre-designed reports are stored within the database and are available by viewing the titles on the **Main form**, then clicking on the desired report in the **Select Report** list box. View or print a copy of the report by clicking either the **Preview** or **Print** button.

Users with knowledge of Access may also create their own reports by using the Access report design tools. All new reports will be displayed in the **Select Report** list box.

Previewing a report displays a print preview of the full report on the screen. View the pages of the report by using the page selector (horizontal arrows next to the word "Page" at the bottom of the print preview window). Click the **Close** button on the toolbar at the top of the main window to exit the report without printing. To print the report, click the printer icon on the toolbar or use the **Print** option in the **File Menu** if multiple copies are desired.

- The **Print** button will send one copy of the report directly to the printer.
- The **Output to File** button on the **Main form** allows the user to export the report to a file in one of three formats: text, rich text, or Excel spreadsheet. When the user clicks the **Output to File** button, a dialog box appears that allows format choices. The program then prompts for a filename and location and exports the file.

Appendix D

Climate Parameters and Evaporation for Bases Contained in the AFCEE Landfill Survey

Installation	State	Precip.[1] (in.)	Pan[2] Evap. (in.)	Pan Coef.[3]	Evap.[4] (in.)	Ratio[5]
George AFB	California	6	110	0.68	74.80	13.36
Williams AFB	Arizona	8	105	0.68	71.40	8.93
March AFB	California	8	70	0.72	50.40	6.00
Castle AFB	California	11	85	0.74	62.90	5.72
Reese AFB	Texas	18	115	0.68	78.20	4.34
Laughlin AFB	Texas	18	110	0.68	74.80	4.16
Goodfellow AFB	Texas	20	103	0.68	70.04	3.42
Vandenberg AFB	California	14	57	0.79	45.03	3.22
F. E. Warren AFB	Wyoming	13	58	0.70	40.60	3.12
Mather AFB	California	17	70	0.74	51.80	3.05
Norton AFB	California	16	70	0.70	49.00	3.04
Travis AFB	California	18	65	0.76	49.40	2.82
Lowry AFB	Colorado	15	58	0.70	40.67	2.77
Sheppard AFB	Texas	26	94	0.70	65.80	2.51
McClellan AFB	California	21	70	0.74	51.80	2.48
Malmstrom AFB	Montana	15	50	0.70	35.00	2.33
Vance AFB	Oklahoma	28	85	0.70	59.50	2.16
Kelly AFB	Texas	30	81	0.70	56.70	1.89
Lackland AFB	Texas	30	81	0.70	56.70	1.89
Randolph AFB	Texas	30	81	0.70	56.70	1.89
Carswell AFB	Texas	32	80	0.70	56.00	1.75
Bergstrom AFB	Texas	32	78	0.70	54.60	1.70
McConnell AFB	Kansas	33	80	0.70	56.00	1.70
Cape Canaveral AS	Florida	45	60	0.77	46.20	1.03
MacDill AFB	Florida	50	65	0.77	50.05	1.00
Bolling AFB	Washington, D.C.	39	47	0.76	35.72	0.92
Scott AFB	Illinois	39	47	0.76	35.72	0.92
Charleston AFB	South Carolina	48	56	0.77	43.12	0.90
Pope AFB	North Carolina	46	55	0.75	41.25	0.89
O'Hare IAP	Illinois	34	39	0.77	30.03	0.88

Installation	State	Precip.[1] (in.)	Pan Evap.[2] (in.)	Pan Coef.[3]	Evap.[4] (in.)	Ratio[5]
Chanute AFB	Illinois	36	41	0.77	31.57	0.88
Tyndall AFB	Florida	55	62	0.77	47.74	0.87
Gentile AFS	Ohio	39	44	0.76	33.44	0.86
Maxwell AFB	Alabama	52	58	0.76	44.08	0.85
England AFB	Lousiana	58	65	0.75	48.75	0.84
Eaker AFB	Arkansas	50	53	0.75	39.75	0.80
Dover AFB	Delaware	44	46	0.77	35.42	0.80
Andrews AFB	Maryland	45	47	0.76	35.72	0.79
Keesler AFB	Mississippi	62	63	0.77	48.51	0.78
Plattsburgh AFB	New York	32	32	0.77	24.64	0.78
Columbus AFB	Mississippi	56	56	0.76	42.56	0.76
McGuire AFB	New Jersey	44	43	0.76	32.68	0.75
Hurlburt Field	Florida	65	60	0.77	46.20	0.71
K. I. Sawyer AFB	Michigan	37	32	0.80	25.60	0.69
Pease AFB	New Hampshire	43	33	0.77	25.41	0.60
Griffis AFB	New York	46	35	0.76	26.60	0.58

[1]Annual precipitation, inches.
[2]Annual class A pan evaporation, inches.
[3]Pan coefficient for converting pan evaporation to potential evaporation (Kohler et al., 1959).
[4]Estimated potential evaporation (Pan Evap. X Coef.), inches per year.
[5]Ratio of annual potential evaporation/annual precipitation (Evap./Precip).

Appendix E

Area of Landfills at Bases Included in the AFCEE Landfill Survey, Arranged by Evaporation Ratio

Only bases and landfills for which data are available in the AFCEE landfill survey were included. Surface area data are missing for 35 landfills. The bases are grouped according to evaporation ratio, those with ratio greater than 1.5, 0.85 to 1.5, and less than 0.85.

Installation	State	Ratio[1]	Rem[2]	Area[3] (ac.)
George AFB	California	13.36	I	61.3
George AFB	California	13.36	C	67.7
Williams AFB	Arizona	8.93	C	34.0
March AFB	California	6.00	C	62.0
Castle AFB	California	5.72	I	105.2
Reese AFB	Texas	4.34	I	32.5
Laughlin AFB	Texas	4.16	C	33.0
Goodfellow AFB	Texas	3.42	C	46.0
Vandenberg AFB	California	3.22	I	88.0
F. E. Warren AFB	Wyoming	3.12	I	130.0
Mather AFB	California	3.05	C	22.2
Norton AFB	California	3.04	I	35.0
Travis AFB	California	2.82	I	116.0
Lowry AFB	Colorado	2.77	I	107.4
Sheppard AFB	Texas	2.51	I	14.0
McClellan AFB	California	2.48	I	17.4
Malmstrom AFB	Montana	2.33	I	30.0
Vance AFB	Oklahoma	2.16	I	2.0
Lackland AFB	Texas	1.89	I	37.3
Lackland AFB	Texas	1.89	C	31.3
Kelly AFB	Texas	1.89	I	136.3
Randolph AFB	Texas	1.89	C	36.0
Carswell AFB	Texas	1.75	C	20.0
Bergstrom AFB	Texas	1.70	C	69.0
McConnell AFB	Kansas	1.70	I	58.5
	Incomplete = 970.9 acres			

Installation	State	Ratio[1]	Rem[2]	Area[3] (ac.)
Cape Canaveral AS	Florida	1.03	I	204.0
MacDill AFB	Florida	1.00	I	15.0
Bolling AFB	Washington, DC	0.92	I	45.0
Bolling AFB	Washington, DC	0.92	C	8.0
Scott AFB	Illinois	0.92	I	60.0
Charleston AFB	South Carolina	0.90	I	14.0
Pope AFB	North Carolina	0.89	I	45.0
O'Hare IAP	Illinois	0.88	I	5.0
Chanute AFB	Illinois	0.88	I	71.0
Tyndall AFB	Florida	0.87	I	132.4
Tyndall AFB	Florida	0.87	C	4.2
Maxwell AFB	Alabama	0.85	I	61.0
	Incomplete = 652.4 acres			
England AFB	Louisiana	0.84	C	4.1
Eaker AFB	Arkansas	0.80	I	113.5
Dover AFB	Delaware	0.80	I	41.6
Andrews AFB	Maryland	0.79	I	12.0
Keesler AFB	Mississippi	0.78	I	50.0
Plattsburgh AFB	New York	0.78	C	27.5
Columbus AFB	Mississippi	0.76	I	13.0
Columbus AFB	Mississippi	0.76	C	39.1
McGuire AFB	New Jersey	0.75	I	33.2
McGuire AFB	New Jersey	0.75	C	40.2
Hurlburt Field	Florida	0.71	I	1.5
K. I. Sawyer AFB	Michigan	0.69	I	65.9
Pease AFB	New Hampshire	0.60	C	39.0
Griffis AFB	New York	0.58	I	51.5
	Incomplete = 382.2 acres			
Total area all available data = 2588.8 acres				

[1]Annual evaporation/annual precipitation
[2]Remediation status, I = incomplete, C = complete
[3]Surface area of landfills, acres

List of Acronyms

ACC	Air Combat Command
AETC	Air Education and Training Command
AFB	Air Force Base
AFBCA	Air Force Base Conversion Agency
AFCEE	Air Force Center for Environmental Excellence
AFIID	Air Force Installation Identification Code
AFMC	Air Force Material Command
AFRES	Air Force Reserve
AFSPC	Air Force Space Command
AMC	Air Mobility Command
ANG	Air National Guard
ARAR	Applicable or Relevant and Appropriate Requirement
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CONUS	Continental United States
DoD	Department of Defense
DRU	Direct Reporting Unit
ERP	Environmental Restoration Program (formerly IRP)
ERPIMS	Environmental Resources Program Information Management System
ET	Evapotranspiration
IRP	Installation Restoration Program (now ERP)
IRPIMS	Installation Restoration Program Information Management System
K	Saturated Hydraulic Conductivity of Soil or Rock
MCL	Maximum Contaminant Level
MAJCOM	Major Command
NCDC	National Climatic Data Center
NCP	National Contingency Plan
NFA	No Further Action
NOV	Notice of Violation
PRG	Preliminary Remediation Goal
RB/PB	Risk-Based/Performance-Based
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act
TCE	Trichloroethylene
USDA	U.S. Department of Agriculture